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**(19) AUSTRALIAN PATENT OFFICE**

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**Controlled oxidation of mineral heaps**

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626709

FORM 1  
REGULATION 9

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

APPLICATION FOR A PATENT

We AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION

of Lucas Heights Research Laboratories, New Illawarra Road, Lucas Heights,  
New South Wales 2234, Australia

hereby apply for the grant of a Patent for an invention entitled:

"OXIDATION OF MINERAL HEAPS

which is described in the accompanying provisional specification.

Our address for service is:

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DATED this 9th day of August, 1989.

AUSTRALIAN NUCLEAR SCIENCE AND  
TECHNOLOGY ORGANISATION

By their Patent Attorneys

*g d h*  
GRIFFITH HACK & CO.

TO: THE COMMISSIONER OF PATENTS  
COMMONWEALTH OF AUSTRALIA

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FORM 8  
COMMONWEALTH OF AUSTRALIA  
PATENTS ACT 1952  
DECLARATION IN SUPPORT OF AN APPLICATION FOR A PATENT

In support of an application made by: AUSTRALIAN NUCLEAR SCIENCE & TECHNOLOGY ORGANISATION

for a patent for an invention entitled: "OXIDATION OF MINERAL HEAPS"

I, Daniel John O'Sullivan  
of, New Illawarra Rd.  
Lucas Heights

do solemnly and sincerely declare as follows:

1. I am authorised by the above mentioned applicant for the patent to make this declaration on its behalf.
2. The name and address of each actual inventor of the invention is as follows:  
  
ALASTAIR IAN MAXWELL RITCHIE; GARRY PANTELIS; JOHN WILLIAM BENNETT and JOHN ROBATHAN HARRIES  
all of Australian Nuclear Science & Technology Organisation,  
Environmental Science Program, Lucas Heights Research Laboratories,  
New Illawarra Road, Lucas Heights, New South Wales, 2234, Australia  
  
and the fact(s) upon which the applicant is entitled to make this application are as follows:  
  
By virtue of Section 34(1)(fa) pursuant to a service agreement between the inventors and the applicant.
3. The basic application as defined by Section 141 of the Act was made in AUSTRALIA on 9 August 1989 in the name AUSTRALIAN NUCLEAR SCIENCE & TECHNOLOGY ORGANISATION.
4. The basic application referred to in the preceding paragraph of this Declaration was the first application made in a Convention country in respect of the invention the subject of this application.

DECLARED at Lucas Heights, New South Wales, Australia

this Thirteenth day of September 1990.

Signed:

Position:

Daniel O'Sullivan  
Intellectual Property Officer

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GH Ref.: P13160HS/COS

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(12) PATENT ABRIDGMENT (11) Document No. AU-B-60837/90  
(19) AUSTRALIAN PATENT OFFICE (10) Acceptance No. 626709

(54) Title  
CONTROLLED OXIDATION OF MINERAL HEAPS  
International Patent Classification(s)  
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(21) Application No. : 60837/90 (22) Application Date : 09.08.90  
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(56) Prior Art Documents  
AU 577794 30533/84 C22B 3/00  
AU 536838 68678/81 C22B 3/00 3/02  
(57) Claim

I. A method of controlling the rate of oxidation of reagents within a mineral heap, comprising:  
taking measurements indicative of physical parameters of the heap;  
analyzing the measurements to predict the fraction of reagent remaining in the heap at some future time;  
predicting what fraction of reagent would remain in the heap at that future time if a measured quantity of one or more control variables were supplied to the heap; and  
then supplying the measured quantity of one of more of the control variables which produce the predicted lower fraction of reagent at that future time;  
wherein the physical parameters include the temperature of the heap and the rate of flow of water through the heap; and  
the control variables include heat and water.

12. A method according to any preceding claim, wherein analyzing the measurements involves inputting measurements to a computer simulation of the oxygen reaction of the reagents within the heap, which uses a mathematical model of the reaction and takes account of all the measured physical parameters.

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22. A method of designing construction of a heap comprising the steps of:

installing instruments as the heap is constructed to take measurements indicative of the physical parameters of the heap;

installing means as the heap is constructed to supply measured quantities of the control variables to the heap;

determining some of the physical parameters of the heap before it is constructed and as it is constructed;

analyzing the determined values to predict what fraction of reagent would remain in the heap at some future time if the value of one or more other physical parameters were varied; and

constructing the heap with said other physical parameters such that the fraction of reagent remaining at that future time is reduced or minimized.

626709

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

Form 10

COMPLETE SPECIFICATION

(ORIGINAL)

FOR OFFICE USE

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Related Art:

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TO BE COMPLETED BY APPLICANT

Name of Applicant: AUSTRALIAN NUCLEAR SCIENCE &  
TECHNOLOGY ORGANISATION

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Illawarra Road, Lucas Heights, New South  
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SYDNEY NSW 2000

Complete Specification for the invention entitled:

"OXIDATION OF MINERAL HEAPS

The following statement is a full description of this invention, including  
the best method of performing it known to me/us:-

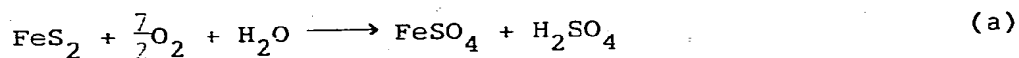
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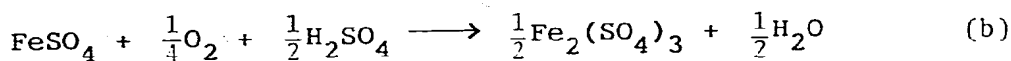
This invention concerns a method of leaching a heap to recover metal, and in particular concerns controlling the rate of oxidation of reagents within a mineral heap. In a second aspect, the invention concerns a method of designing construction of a heap for leaching.

The leaching of metals such as copper, nickel, zinc and uranium from some ores depends on the conversion (oxidation) of largely insoluble metal sulphides to the much more soluble sulphates. The process is usually carried out in large heaps of sulphidic material through which water is passed. The water dissolves the metal sulphates and passes out through the base of the heap where it is processed to remove the metal of economic interest. The process is essentially one of concentration and is generally applied to low grade ores where conventional hydrometallurgical or pyrometallurgical techniques are uneconomic. Crucial to the solubilisation process is bacterially catalysed oxidation of iron pyrite or other iron containing pyrites.

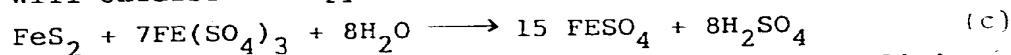
The oxidation of pyrite to ferrous sulphate can be described by the equation,



The oxidation of ferrous sulphate to ferric sulphate can in turn be described by,



Under the correct chemical conditions ferric sulphate will oxidise more pyrite according to the equation



The last two equations describe an autocatalytic process which is also catalysed by the intervention of microorganisms which speed up the second reaction.

Ferric sulphate will also convert other metallic sulphides to sulphates according to the general equation,

$$\text{MS} + 2\text{Fe}_2(\text{SO}_4)_3 + 2\text{H}_2\text{O} + \text{O}_2 \longrightarrow \text{MSO}_4 + 4\text{FeSO}_4 + 2\text{H}_2\text{SO}_4 \quad (\text{d})$$

It is also known that the extraction efficiency of gold from many auriferous sulphide ores is greatly increased if the ore is first oxidised. This can be effected in a heap, where the oxidation process can be described by equations (b) and (c) above.

In an industrial heap, which may measure tens to hundreds of meters in height, the oxidation rate is limited by the rate at which oxygen can be supplied to the sites of unreacted pyrite.

Initially oxygen will enter the heap from the atmosphere/heap interface by the process of molecular diffusion. At this time, the oxidation reaction is confined to the surface layers of the heap. The heat released from the pyritic reaction will induce a convective air current within the heap and in so doing will increase the rate of atmospheric oxygen transport into the heap and permit oxidation throughout the heap. The oxygen supply to the heap is believed to be the limiting factor of the oxidation reaction.

According to a first aspect of the present invention, there is provided a method of controlling the rate of oxidation of reagents within a mineral heap, comprising:

taking measurements indicative of physical parameters of the heap;

analyzing the measurements to predict the fraction of reagent remaining in the heap at some future time;

predicting what fraction of reagent would remain in the heap at that future time if a measured quantity of one or more control variables were supplied to the heap; and

then supplying the measured quantity of one of more of the control variables which produce the predicted lower fraction of reagent at that future time;

wherein the physical parameters include the temperature of the heap and the rate of flow of water through the heap; and

the control variables include heat and water.

Taking measurements indicative of the temperature of the heap includes taking the temperature at each point of an



array distributed throughout the heap or part of the heap. It also includes non-invasive techniques of obtaining measurements indicative of temperature, such as those employing infra-red detection.

5           Taking measurements indicative of the rate of flow of water through the heap (irrigation rate) includes measuring the net volume of water flowing from the bottom of the heap, and measuring the rates of flow in particular directions at points throughout the heap or parts of the heap.

10           Measurements may also be taken indicative of oxygen concentration, pyrite concentration, air pressure, particle size and the geometry of the heap. All these variables have an effect on the convective and diffusive transport of oxygen into the heap. Measurements may also be taken to  
15           determine gas permeability and diffusion coefficients in the heap.

          Analyzing the measurements includes weighting, averaging or otherwise adjusting the measurements, and preferably includes inputting the measurements to a  
20           simulation of the oxidation reaction of the reagents within the heap. The simulation would usually be performed on a computer using a mathematical model of the oxidation reaction. The simulation will advantageously take into account all the measured physical parameters of the heap.

25           Supplying a measured quantity of one or more of the control variables changes the amount of heat in the heap. The heat in the heap may be increased by direct means, such as electric heating elements positioned in an array  
30           throughout the heap, or a selected portion of the heap such as the bottom 1 metre; it may also be supplied by irradiating the heap, say, with microwave radiation.

          Heat may be indirectly supplied to the heap by increasing the convection rate of air or oxygen in the heap, for instance by injecting air or oxygen through pipes into  
35           the interior of the heap. Air or oxygen may, of course, be included in the list of control variables.

          Removing heat from the heap can be achieved by increasing the flow of water through the heap, such as by pouring or sprinkling water onto the heap, or injecting

water into the heap from an array of nozzles arranged throughout the heap or a portion of it.

Water flowing through the heap cools it in two ways. Firstly, it removes heat directly by absorbing thermal heat and latent heat. Secondly, it removes heat by obstructing the interparticular space in the heap and slowing convection.

It is important that both heat supply and heat removal are controlled since too much heating could raise the temperature within the heap to a point where the micro-organisms cease to be effective as catalysts, but too little heat will slow down the oxidation reaction.

Advantageously, local environmental and economic factors are also taken into account; environmental factors include the precipitation rate, and the evaporation rate. Ideally, measurements indicative of these factors will be taken and supplied to the simulation.

The analyzing and predicting steps are preferably repeated at regular intervals, under the control of an operator.

Optionally, the method includes the step of installing instruments in the heap to take measurements indicative of the physical parameters. Also, a step of installing means to effect the supply of the control variables may be included.

According to a second aspect of the present invention as currently envisaged, there is provided a method of designing construction of a heap comprising the steps of:

installing instruments as the heap is constructed to take measurements indicative of the physical parameters of the heap;

installing means as the heap is constructed to supply measured quantities of the control variables to the heap;

determining some of the physical parameters of the heap before it is constructed and as it is constructed;

analyzing the determined values to predict what fraction of reagent would remain in the heap at some future time if the value of one or more other physical parameters were varied; and

constructing the heap with said other physical parameters such that the fraction of reagent remaining at that future time is reduced or minimized.

5 The invention will now be described by way of example only with reference to the accompanying drawing, which is a graph showing the behaviour of a heap under various circumstances.

10 Instruments are applied to a heap to measure the gas concentration, pyrite concentration, temperature, irrigation rate (flow of water through the heap), air pressure, and particle size; the geometry of the heap is also measured.

Measuring these variables serves two purposes. Firstly, it monitors changes in the heap as the oxidation proceeds; and secondly, it allows values to be generated which are fed to a computer model to obtain predictions of the future behaviour of heap. An operator will decide at what intervals it is appropriate to feed parameters to the computer model.

20 The computer model is able to simulate the oxidation reaction in the heap based on the information received about the physical parameters. The prediction is usually expressed in terms indicative of the fraction of reagent left in the heap when compared to some reference date. The fraction of reagents left within the heap may be indirectly expressed in terms of some convenient statistic which, for the purpose of convenience, is called the global oxidation rate or GOR.

25 The reference date may be selected in any convenient manner. For instance, the reference date could be the date metal recovery commenced, or the date of the analyzing step. The date may be changed every time the analyzing step is performed, or may remain static in time throughout all or part of the metal recovery process.

30 In general, the operator will decide from the information available to him (about the physical parameters, the environmental factors and any relevant economic constraints), whether it is appropriate to increase the

temperature within the heap or to reduce the temperature within the heap. If the operator decides an increase in temperature is called for, he will estimate what quantity of heat to supply to the heap, whether to supply it directly, or indirectly by reducing irrigation or increasing air or oxygen convection, and how it is to be distributed within the heap. He will then model the behaviour of the heap using a computer model to predict the likely effect of the change estimated. When an estimated change produces an acceptable prediction, the operator will cause that change to be effected.

If the operator decides a reduction in the temperature in the heap is called for, he may do this by reducing the amount of heat supplied, by supplying water to the heap, or by reducing the supply of air or oxygen to the heap. He will then go through the estimation and modelling procedure until a desired result is predicted, and then effect the appropriate change.

The computer model is based on a deterministic formulation of multiphase flow through porous media as follows:

The mass balance equations for each phase

$$\alpha = g, l, s$$

(g  $\equiv$  gas(air), l  $\equiv$  liquid(water), s  $\equiv$  solid (heap ore)) are given by

$$\frac{\partial \rho_{\alpha}}{\partial t} + \nabla \cdot (\rho_{\alpha} \underline{v}^{\alpha}) = W_{\alpha} \quad (1)$$

where  $\rho_{\alpha}$  is the bulk density of the  $\alpha$  phase and is related to the intrinsic density  $\rho_{\alpha}$  by

$$\rho_{\alpha} = \epsilon_{\alpha} \rho^{\alpha} \quad (2)$$

where  $\epsilon_{\alpha}$  is the volume fraction of the  $\alpha$  phase such that

$$\sum_{\alpha} \epsilon_{\alpha} = 1 \quad (3)$$

The quantity  $W_\alpha$  on the right hand side of (1) is an external source/sink of the  $\alpha$  phase. For the liquid and gas phases Darcy's Law is assumed:

$$\epsilon_\alpha \underline{v}^\alpha = - \frac{K k_{r\alpha}}{\mu_\alpha} (\nabla p_\alpha + \rho_\alpha g \underline{e}_z) \quad (4)$$

where  $K$  is the saturated permeability;  $k_{r\alpha}$  is the relative permeability of the  $\alpha$  phase which is some function of  $\epsilon_\alpha$ ;  $p_\alpha$  is the pressure of the  $\alpha$  phase;  $\mu_\alpha$  is the viscosity of the  $\alpha$  phase;  $g$  the acceleration due to gravity and  $\underline{e}_z$  is the unit vector pointing vertically upwards. We assume that

$$\underline{v}^s = 0 \quad (5)$$

and that  $\rho_s$  and  $\epsilon_s$  are constant despite the loss of mass to the solid phase due to the oxidation of the pyrite.

The mass balance equation for a species  $i \in \{1, \dots, n_\alpha\}$  in the  $\alpha$  phase is given by

$$\rho_\alpha \frac{\partial \omega_i^\alpha}{\partial t} + \rho_\alpha \underline{v}^\alpha \cdot \nabla \omega_i^\alpha + \nabla \cdot \underline{J}_i^\alpha = \rho_\alpha I_i^\alpha + G_i^\alpha \quad (6)$$

where  $\omega_i^\alpha$  is the mass fraction of the species  $i$  in the  $\alpha$  phase;  $\underline{J}_i^\alpha$  is the nonadvective flux vector for species  $i$  in the  $\alpha$  phase,  $I_i^\alpha$  is the diffusive mass fluxes across the phase interfaces and  $G_i^\alpha$  is an external source/sink term of the species  $i$  in the  $\alpha$  phase.

In the gas phase, we consider only the oxygen specie so that

$$\rho_g \frac{\partial \omega^g}{\partial t} + \rho_g \underline{v}^g \cdot \nabla \omega^g - \nabla \cdot (\rho_g D_g \nabla \omega^g) = \rho_g I^g + G^g \quad (7)$$

where  $\omega^g$  is the mass fraction of oxygen in the gas phase and the subscript  $i$  has been dropped since only one specie is considered.  $G^g$  is the injected oxygen. The nonadvective flux vector  $\underline{J}^g$  is assumed to be described by the Fickian law

$$\underline{J}^g = -\rho_g D_g \nabla \omega^g \quad (8)$$

where  $D_g$  is the coefficient of diffusion of oxygen in the porous medium. It should be noted that we have ignored dispersion which could be significant when convection gets going. This exclusion should not be seen as a restriction to the model as it is straight forward to insert it at a later stage.

The pyrite is fixed in the solid phase so that (6) reduces to

$$\rho_s \frac{d\omega^s}{dt} = \rho_s I^s \quad (9)$$

where  $\omega^s$  is the mass fraction of pyrite in the solid phase and again the subscript  $i$  has been dropped since there is only one specie considered in the solid phase. Note that here we exclude any external source/sink terms.

The energy equation for the porous medium is given by

$$\sum_{\alpha} \rho_{\alpha} c_{\alpha} \frac{\partial T}{\partial t} + \sum_{\alpha} c_{\alpha} \rho_{\alpha} v_{\alpha}^{\alpha} \cdot \nabla \cdot (D_h \nabla T) = S + S_{ext} \quad (10)$$

where  $T$  is the temperature;  $c_{\alpha}$  is the specific heat capacity of the  $\alpha$  phase;  $D_h$  is the thermal conductivity in the porous medium (all phases),  $S$  is the heat produced by the oxidation reaction and  $S_{ext}$  is the externally applied heat.

Both  $\rho^s$  and  $\rho^l$  are assumed to be constant whereas the intrinsic gas density is assumed to be a function of temperature through

$$\rho^g = \rho_0^g (1 - \alpha T) \quad (11)$$

where  $\rho_0^g$  is the atmospheric air density and  $\alpha$  is the coefficient of thermal expansion.

The boundary conditions are obtained by setting the oxygen concentration, temperature and air pressure at their atmospheric values at the atmosphere/heap interface. On the upper boundary of the heap is imposed a flux condition.

$$-\frac{Kk_{fl}}{\mu l} (\nabla p_l + \rho^l g e_z) \cdot n = -\rho^l g (Q_R + Q_I) \quad (12)$$

which induces vertical water infiltration which is assumed to be drained at the base of the heap. In (12)  $Q_R$  is the net input of water by rainfall/evaporation and  $Q_I$  the input by artificial means.

5           Upon incorporation of the constitutive relations of (2), (3), (4) and (11) the 2 equations of (1)  $\alpha = g, l$ ; equations (7) and (9) and the heat equation (10) constitute a system of 5 equations for the 5 variables  $p_g, p_l, \omega^g, \omega^s$  and  $T$ . We define the "natural" operation of the  
10   above heap system when there exists no artificial inputs/outputs  $Q_I, S_{ext}, G^g, W_\alpha$  ( $\alpha = l, g$ ). Under these natural conditions, diffusion will initially be the only means of transport of oxygen to reaction sites within the heap. As the heat of oxidation builds up convection  
15   will develop and raise the GOR. The extent to which both diffusion and convection are effective in transporting oxygen into the heap will depend on the physical parameters which define the particular heap system under consideration. The physical parameters which are particular  
20   to each heap are contained in a set

$$P \equiv \{ \rho_s, K, \epsilon_s, \omega^s |_{t=0}, D_g, c_s, D_h, k_{r\alpha}(\epsilon_\alpha) (\alpha = l, g), Q_R, \\ 1$$

$$I^g(\omega^g, \omega^s, T), I^s(\omega^g, \omega^s, T), S(\omega^g, \omega^s, T) L^1, \dots, L^m.$$

25   The interdependent quantities  $I^g, I^s, S$  define the oxidation rates and heat rate of reactions and are defined by a set of parameters which must also be included in the set  $P$ . These reaction parameters will depend largely on the microscopic structure of the medium. Also in the set  $P$  we  
30   include a set of parameters  $L_1, \dots, L_m$  which define the geometry of the heap. For the example of a cylindrical heap this set will simply contain the radius  $R_0$  and the height  $Z_0$ .

35   In a preferred form of the second aspect of the invention, the heap is constructed with instrumentation for monitoring. Simulations using the computer model are performed prior to construction of the heap in order to decide on an optional set of heap parameters defined in  $P$ . This may entail modification of run of mine material. Then

the heap is allowed to operate over a specified time interval after which the current variables  $p_g$ ,  $p_l$ ,  $\omega^g$ ,  $\omega^s$ ,  $T$  are measured. These are then fed as initial data into the computer model which simulates the evolutionary behaviour of the operation and after a series of runs the operator decides on a course of action which will increase the GOR. Some decision making facilities could be incorporated in the model. The course of action is effected by the special variation of one or more of the artificial input quantities  $Q_I$ ,  $S_{ext}$ ,  $G^g$ ,  $W_\alpha$  ( $\alpha=l, g$ ).

The computer model is based on a finite difference solution of the mathematical formulation described above corresponding to a set  $P$  of specified parameters. Given a set of initial data for the variables  $p_g$ ,  $p_l$ ,  $\omega^g$ ,  $\omega^s$  and  $T$  (which are obtained by insitu measurement), the computer model is run to simulate a specified time interval. At the end of this time interval, the computer program computes the current GOR. If there is no increase in the GOR the operator will rerun the computer model with changes in one or more of the artificial parameters  $Q_I$ ,  $S_{ext}$ ,  $W_\alpha$  ( $\alpha=l, g$ ) such that the GOR is increased in the next time interval of the heap operation. Some optimization features could be incorporated in the model. This procedure is repeated sequentially until either the pyrite in the heap is depleted or the heap operation is halted by the operator.

Although the invention has been described with reference to preferred embodiments, it should be appreciated that it could be performed in many other ways, for instance, the mathematical description of the procedure could also include the chemical species in the liquid (water) phase. The transport of any chemical specie, of mass fraction  $\omega_i^l$ ,  $i=1, \dots, n_l$ , is governed by  $n_l$  equations of (6) with  $\alpha=l$ . A term  $p_l r_i$  term should be included on the right hand side of (6) for  $\alpha=l$  to account for homogeneous reactions of the species  $i$  within the liquid phase.) Here  $G_i^l$  must be included in the set of artificial inputs and the variables  $\omega_i^l$ ,  $i=1, \dots, n_l$ , are added to the set of monitored variables of the heap.



Referring now to Figure 1:

(1) shows the behaviour of the heap with no artificial heating and no irrigation.

5 (2) shows the behaviour of the heap with continuous artificial heating to the bottom 1 metre of the heap at  $100 \text{ W/m}^3$  and no irrigation. This graph shows an initial improvement of the GOR over (1) but overheating eventually retards the GOR.

10 (3) shows the behaviour of the heap with an irrigation rate of 0.1 m per hour and no heating. In this case, heat has been removed from the heap and convection has been reduced which results in a decreased GOR.

15 (4) shows the behaviour of the heap with an irrigation rate of 0.01 m/hour and heat supplied to the bottom 1 metre of the heap at a rate of  $100 \text{ W/m}^3$ . In this case, significant air flow has been induced which results in overheating and the reaction switching off. However, it is worth noting that there is some improvement over the situation where only the heat was applied (2) and the situation where only the irrigation was supplied (3).

20 (5) shows the behaviour of the heap with an irrigation rate of  $10^{-3}$  m/hour with no artificial heating, and this shows a considerable improvement over the natural state.

25 (6) shows the results obtained from a process embodying the present invention, where the irrigation rate is tailored at regular time intervals. This shows considerable improvements over all previous results.

30 (7) also shows the result of a process embodying the present invention. Here, the bottom 1 metre of the heap was artificially heated according to a predicted amount and a constant rate of artificial irrigation of 0.1 m per hour was applied.

35

**CLAIMS**

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of controlling the rate of oxidation of reagents within a mineral heap, comprising:

taking measurements indicative of physical parameters of the heap;

analyzing the measurements to predict the fraction of reagent remaining in the heap at some future time;

predicting what fraction of reagent would remain in the heap at that future time if a measured quantity of one or more control variables were supplied to the heap; and

then supplying the measured quantity of one of more of the control variables which produce the predicted lower fraction of reagent at that future time;

wherein the physical parameters include the temperature of the heap and the rate of flow of water through the heap; and

the control variables include heat and water.

2. A method according to claim 1, wherein taking measurements indicative of the temperature of the heap involves taking the temperature at each point of an array distributed throughout the heap.

3. A method according to claim 1, wherein taking measurements indicative of the temperature of the heap involves infra red detection.

4. A method according to any preceding claim, wherein taking measurements indicative of the irrigation rate involves measuring the net volume of water flowing from the bottom of the heap.

5. A method according to any one of claims 1 to 3, wherein taking measurements indicative of the irrigation rate involves measuring the rates of flow particular directions of points throughout the heap.

6. A method according to any preceding claim wherein measurements indicative of oxygen concentration are taken.

7. A method according to any preceding claim, wherein measurements indicative of pyrite concentration are taken.

5 8. A method according to any preceding claim, wherein measurements indicative of air pressure are taken.

9. A method according to any preceding claim, wherein measurements indicative of particle size are taken.

10 10. A method according to any preceding claim, wherein measurements are taken of the geometry of the heap.

11. A method according to any preceding claim, wherein measurements are taken to determine gas permeability and diffusion coefficients in the heap.

12. A method according to any preceding claim, wherein analyzing the measurements involves inputting  
15 measurements to a computer simulation of the oxygen reaction of the reagents within the heap, which uses a mathematical model of the reaction and takes account of all the measured physical parameters.

13. A method according to any preceding claim, wherein the heat in the heap is increased by direct means.  
20

14. A method according to any one of claims 1 to 12, wherein heat is indirectly supplied to the heap by increasing the convection rate of air or oxygen in the heap.

25 15. A method according to any preceding claim, wherein the control variables include air.

16. A method according to any preceding claim, wherein the control variables include oxygen.

17. A method according to any preceding claim, wherein removing heat from the heap is achieved by  
30 increasing the flow of water through the heap.

18. A method according to any preceding claim, wherein the analyzing and predicting steps are repeated at regular intervals under control of an operator.

19. A method according to any preceding claim, wherein the method includes the step of installing  
35 instruments in the heap to take measurements indicative of the physical parameters.

20. A method according to any preceding claim,  
wherein the method includes the step of installing means to  
effect the supply of the control variables.

21. A method of controlling the rate of oxidation  
of reagents within a mineral heap substantially as  
hereinbefore described with reference to the accompanying  
drawings.

22. A method of designing construction of a heap  
comprising the steps of:

installing instruments as the heap is constructed to  
take measurements indicative of the physical parameters of  
the heap;

installing means as the heap is constructed to supply  
measured quantities of the control variables to the heap;

determining some of the physical parameters of the  
heap before it is constructed and as it is constructed;

analyzing the determined values to predict what  
fraction of reagent would remain in the heap at some future  
time if the value of one or more other physical parameters  
were varied; and

constructing the heap with said other physical  
parameters such that the fraction of reagent remaining at  
that future time is reduced or minimized.

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AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION

By their Patent Attorneys  
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**DRAWINGS**

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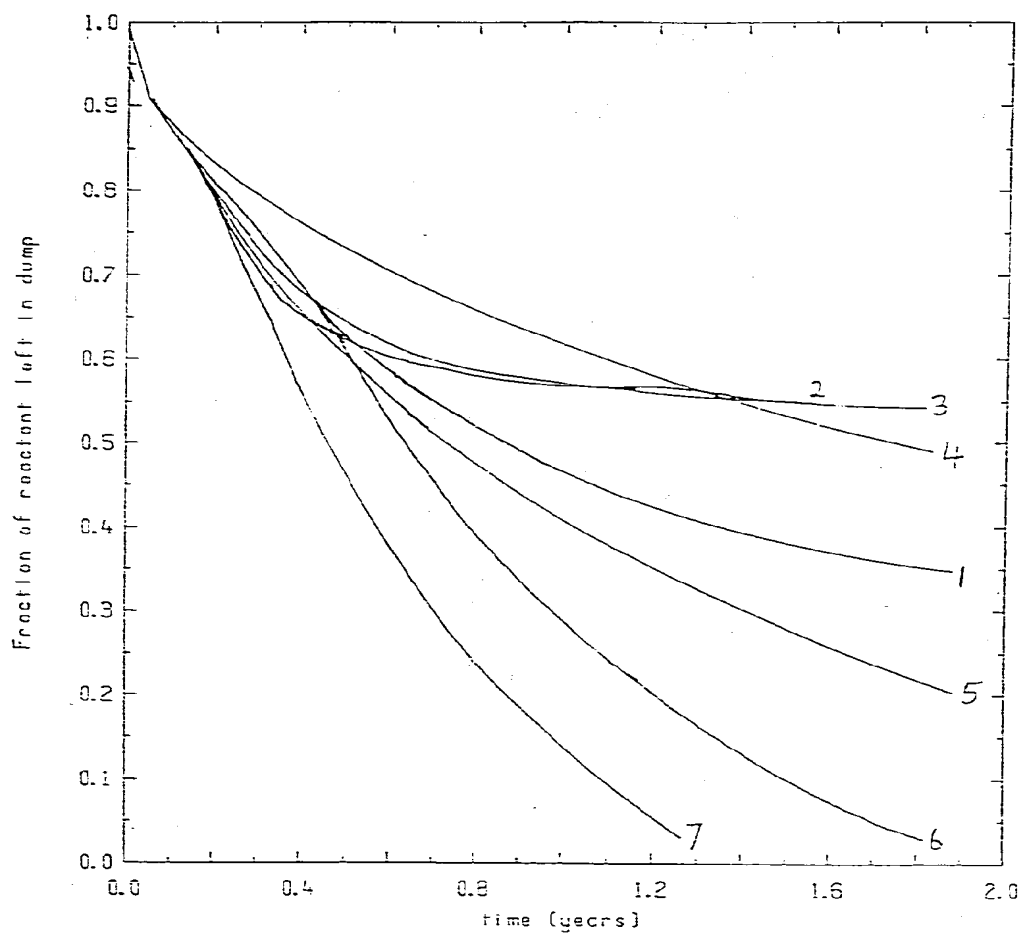


FIGURE 1